Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price

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Applying a model of the multioutput firm, econometric results are reported for irrigated production in four multistate regions of the American West. Cross-sectional microdata from the Farm and Ranch Irrigation Survey and limited-dependent variable methods are used to estimate crop-choice, supply, land allocation, and water demand functions for field crops. Farm-level water demand is decomposed into the sum of crop-level water demands, and crop-level demands are further separated into an extensive margin (land allocations) and intensive margin (short-run water use). Response to water price (measured as groundwater pumping cost) occurs primarily at the extensive margin.

Key words: irrigation, limited-dependent variables, multioutput production, water demand, water price, western United States.

The American West has moved irrevocably into the age of water scarcity. Physical limits to water-supply development and increasing intersectoral competition for water characterize the setting of scarcity. As the dominant consumer of water, western irrigated agriculture will now encounter incentives for water conservation. A variety of incentives already exist, with more continuing to be created by market signals or developed as public policy. They include: increased groundwater pumping costs caused by declining aquifer levels; higher market prices for voluntary water transfers; higher contract prices and/or reduced entitlements for federal Reclamation water supplies; and environmental constraints on irrigation water use.

Irrigators conserve water in a variety of ways in response to incentives reflecting water scarcity. The last decade produced a body of econometric evidence on the role of input-use adjustments as a response to higher water prices or reduced water entitlements. Recent studies established empirical evidence on the price elasticity of demand for irrigation water (Nieswiadomy; Ogg and Gollehon); quantified the effect of water price on irrigation development, irrigation technology choice, or irrigation technology demand (Caswell and Zilberman; Negri and Brooks; Nieswiadomy; Schaible, Kim, and Whittlesey); and estimated the effect of a reduced water entitlement on cropland allocation decisions of Reclamation-served irrigators (Moore and Negri). Collectively, this research establishes that producers adapt rationally to water-scarcity signals.

Several features of producer's response to higher water prices remain to be investigated empirically. First, the opportunity for output substitution has not been studied with econometric techniques. Since most irrigated production occurs in a multioutput enterprise, altering the mix of crop outputs offers an important adaptive strategy. Second, the relative importance of the extensive margin of water use

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(cropland allocation decisions) and the intensive margin (short-run water application decisions) has not been examined econometrically. In particular, land allocation decisions may increase or decrease in water price depending on the crop. And third, regional differences in producer behavior have not been studied. Regional differences in parameters of the underlying multioutput technology (in the sense of Chambers, Chap. 7) would create behavioral differences. Whether technologies differ across regions can be tested statistically through comparison of behavioral equations across regions.

We conduct an econometric analysis of irrigated production in the western United States. The analysis encompasses multicrop farm firms that produce common field crops in four regions of the western United States (Northwest, Central Plains, Southern Plains, and Southwest). The research applies a model of the multioutput farm enterprise in which a fixed, allocatable land constraint provides the source of jointness in production decisions (Chambers and Just; Just, Zilberman, and Hochman; Shumway, Pope, and Nash). With this model, land allocation, short-run water demand, and crop supply equations are derived and estimated using cross-sectional data from the 1984 and 1988 Farm and Ranch Irrigation Surveys and limited-dependent variable econometric methods. In an era of water scarcity, understanding the influence of water price on water-conserving activity is a key contribution to policy evaluation.

A Multicrop Model of Irrigated Agricultural Production

Producers engaged in irrigated agriculture make a variety of decisions concerning crop-choice, land use, and irrigation water application.[1] A producer chooses which crops to grow from a set of m irrigated field crops common to a region. Each producer typically grows two or more crops, yet does not necessarily grow all m crops. Thus, the crop-choice decision can be studied independently as a discrete choice. Along with the crop-choice decision, the producer decides the quantity of cropland to allocate to each crop. In this sense, crop-choice and land-use decisions follow a two-part description of behavior: decisions are decomposed into whether to "participate" in growing a crop and how much acreage of land to allocate to the crop given participation (Maddala, Chap. 9). Crop supply decisions are treated similarly. As an irrigator, the producer also makes crop-level water decisions; these are conditional on land allocations, thus reflecting water use within an irrigation season. The crop-choice, land allocation, and supply decisions are modeled as relatively long-run decisions, while crop-level water demand is modeled as a short-run decision.

Model

The model applies the theory of the multioutput competitive firm to a farm enterprise engaged in irrigated production. We assume input nonjointness in production and a farm-level constraint on land with irrigation infrastructure. Input nonjointness enables characterization of crop-level profit functions. Irrigation water is a variable input since groundwater is available to the farms as the marginal water source. Marginal cost of groundwater pumping serves as the measure of water price (as in Caswell and Zilberman; Negri and Brooks; Nieswiadomy; Ogg and Gollehon).

The following notation and assumptions apply: $\mathbf{p}$ is a vector of crop prices; p_i is the price of crop i, $i = 1, ..., m$; $\mathbf{r}$ is a vector of variable input prices except for water price; b is the irrigation water price; N is the land constraint; $\mathbf{x}$ is a vector of other variables exogenous to the farm or crop (climate, weather, soil quality, and irrigation technology); n_i is the land allocated to crop i; w_i is the irrigation water applied to crop i; y_i is the output of crop i; $\Pi(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})$ is the multioutput profit function; and $\pi_i(p_i, \mathbf{r}, b, n_i; \mathbf{x})$ is the crop-level restricted profit function of crop i. The $\pi_i(p_i, \mathbf{r}, b, n_i; \mathbf{x})$ are assumed convex and homogeneous of degree one in p_i, $\mathbf{r}$, and b, nondecreasing in p_i and n_i, and nonincreasing in $\mathbf{r}$ and b. Producers take prices as given.

The study applies the normalized quadratic profit function as the form of the crop-specific restricted profit functions. The normalized quadratic is a flexible functional form (Lau), and has been applied previously to multioutput agricultural production research (e.g., Huffman, Shumway). Its full specification includes linear, squared, and cross-product terms for all exogenous variables. Prices are expressed as relative prices to maintain linear homogeneity of the

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[1] This research does not analyze farm-level irrigation technology choice. Negri and Brooks analyzed this as a discrete choice and Nieswiadomy estimated irrigation technology demand functions. Farm-level irrigation technology is modeled as a fixed input in the current paper.

profit function.[2]

The crop-choice decision simply involves a discrete choice on whether to grow a particular crop. Among other variables, the decision depends on all output prices, water price, the land constraint, and climate variables. Rather than developing a formal model, the decision is stated as

$$(1) \quad d_i = f_i(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x}) \qquad i = 1, \ldots, m$$

where d_i is a discrete-choice variable equal to 1 if crop i is grown and 0 if it is not grown.

The remaining model elements are developed in a formal multioutput framework. To obtain the land allocation functions, we solve the producer's problem of optimally allocating land among crops subject to the land constraint (Chambers and Just, p. 982; Shumway, Pope, and Nash, p. 77). The constrained optimization problem representing this decision is

$$(2) \quad \Pi(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x}) = \max_{n_1 \ldots n_m} \left\{ \sum_{i=1}^{m} \pi_i\left(p_i, \mathbf{r}, b, n_i; \mathbf{x}\right) : \sum_{i=1}^{m} n_i = N \right\}.$$

The two elements of an equation system for solving (2) are the first-order conditions for an interior solution ($\partial\pi_i(p_i, \mathbf{r}, b, n_i; \mathbf{x})/\partial n_i = \lambda$ for $i = 1, \ldots, m$, where λ is the shadow price on the land constraint) and the land-constraint equation. Optimal land allocation functions, $n_i^*(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})$, follow from solving the equation system explicitly for an interior solution. Given the normalized quadratic form for the profit functions, the $n_i^*(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})$ that solve equation (2) are linear in the exogenous variables (Moore and Negri, p. 31–33). Thus, the estimable forms are

$$(3) \quad n_i^* = \alpha^i + \sum_{j=1}^{m} \beta_j^i p_j + \sum_{v=1}^{z} \gamma_v^i r_v + \delta^i b + \psi^i N + \sum_{s=1}^{t} \eta_s^i x_s \qquad i = 1, \ldots, m.$$

In contrast to the land allocation functions, crop supply and water demand functions follow directly from standard duality results. Begin by writing the multicrop profit function in (2) as

$$(4) \quad \Pi(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x}) = \sum_{i=1}^{m} \pi_i[p_i, \mathbf{r}, b, n_i^*(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x}); \mathbf{x}].$$

Supply functions result from applying Hotelling's lemma to (4). Two forms are possible

$$(5) \quad y_i(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x}) = \frac{\partial\Pi(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})}{\partial p_i} = \frac{\partial\pi_i(p_i, \mathbf{r}, b, n_i^*; \mathbf{x})}{\partial p_i} = y_i(p_i, \mathbf{r}, b, n_i^*; \mathbf{x}) \qquad i = 1, \ldots, m.$$

As an application of the envelope theorem, these forms are equivalent (Chambers and Just, p. 982). We apply $y_i(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})$ because the crop prices are treated explicitly rather than embedding some of their effect in the $n_i^*(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})$ term of $y_i(p_i, \mathbf{r}, b, n_i^*; \mathbf{x})$. Short-run water demand functions follow from applying Hotelling's lemma to the crop-specific profit functions

$$(6) \quad -\frac{\partial\pi_i(p_i, \mathbf{r}, b, n_i; \mathbf{x})}{\partial b} = w_i(p_i, \mathbf{r}, b, n_i; \mathbf{x}), \qquad i = 1, \ldots., m.$$

Thus, water is modeled as a variable input in the short run, as in previous research on irrigated agriculture (Chambers and Just; Just, Zilberman, and Hochman). With normalized quadratic forms for $\pi_i(p_i, \mathbf{r}, b, n_i; \mathbf{x})$, the estimable forms for $y_i(\mathbf{p}, \mathbf{r}, b, N; \mathbf{x})$ and $w_i(p_i, \mathbf{r}, b, n_i; \mathbf{x})$ are linear in the exogenous variables, or

$$(7) \quad y_i = \theta^i + \sum_{j=1}^{m} \kappa_j^i p_j + \sum_{v=1}^{z} \xi_v^i r_v + \tau^i b + \rho^i N + \sum_{s=1}^{t} \upsilon_s^i x_s \qquad i = 1, \ldots., m.$$

and

$$(8) \quad w_i = \mu^i + \nu^i p_i + \sum_{v=1}^{z} \omega_v^i r_v$$

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[2] To simplify notation, the reader should interpret output and input prices for the estimated supply, demand, and allocation functions as relative prices when they are written in the context of being derived from normalized quadratic profit functions.

$$+ \varphi^{i} b + \vartheta^{i} n_{i} + \sum_{s=1}^{t} \iota_{s}^{i} x_{s} \qquad i = 1, \ldots., m.$$

Note three general items illustrated by the choice functions. First, in models assuming input nonjointness, nonzero cross-price effects signal the apparent jointness created by fixed, allocatable inputs (Chambers and Just; Shumway, Pope, and Nash). With the current model, the output-price terms in the supply functions and the land allocation functions illustrate the jointness created by the fixed land input. Second, the supply and land allocation functions also capture information on possible output substitutions in response to water price. Finally, the water demand and land allocation functions show a strength of assuming input nonjointness: crop-level land and water use data can be utilized econometrically. With input jointness, in contrast, the multioutput profit function does not decompose into crop-specific profit functions. Only farm-level variable input demand functions can be specified and estimated as a consequence.

Decomposing Farm-level Water Demand

This research emphasizes the role of water price as a determinant of producer decisions because of its importance to water conservation policy. With farm-level data, only farm-level water demand of multicrop producers can be analyzed. With crop-level data, in contrast, farm-level water demand can be decomposed into the sum of crop-specific water demands. Moreover, crop-level water use can be further separated into analysis of the extensive margin of water use (the land allocation decision) and the intensive margin of water use (short-run water demand).

This depiction of the effect of price on decisions can be shown analytically by first representing farm-level water use (W) using the water demand and land allocation equations

$$(9) \qquad W = \sum_{i=1}^{m} w_{i}[p_{i}, \mathbf{r}, \; b, n_{i}^{*}(\mathbf{p}, \mathbf{r}, \; b, N; \mathbf{x}); \mathbf{x}].$$

Totally differentiating (9) with respect to water price then yields

$$(10) \qquad \frac{dW}{db} = \sum_{i=1}^{m} \left(\frac{\partial w_{i}}{\partial b} + \frac{\partial w_{i}}{\partial n_{i}^{*}} \frac{\partial n_{i}^{*}}{\partial b} \right).$$

In this way, crop-level response decomposes into an intensive margin (a direct effect operating through short-run water demand) and an extensive margin (an indirect effect operating through land reallocation). Summing over the m crops results in the farm-level response. Equation (10) shows that the total effect of a price increase on crop-level water use may be positive or negative. According to comparative static results, the intensive margin should decrease in price. Yet, the extensive margin may increase or decrease depending on the sign of $\partial n_{i}^{*}/\partial b$. The total farm-level effect, i.e., summing across crops, should be that farm-level water demand decreases in water price.

Data and Econometric Methods

Data and Variables

The econometric analysis compares two types of multicrop producers distinguished by the set of irrigated field crops being produced. One type of producer chooses among five crops: alfalfa hay, barley, corn for grain, dry beans, and wheat. Two regions of the West contain these producers, the Northwest (Idaho, Oregon, and Washington) and the Central Plains (Colorado, Kansas, Nebraska, and Wyoming). The second type of producer chooses among a slightly different set of crops: alfalfa hay, corn for grain, cotton, grain sorghum, and wheat. Two regions of the West contain these producers, the Southern Plains (eastern New Mexico, Oklahoma, and Texas) and the Southwest (Arizona, California, and western New Mexico).

The primary data are cross-sectional data from the 1984 and 1988 Farm and Ranch Irrigation Survey (FRIS), a survey of operators of irrigated farms (U.S. Department of Commerce, 1986, 1990). The 1984 (1988) FRIS samples respondents to the 1982 (1987) Census of Agriculture who reported irrigated land. The survey includes questions on output (y_{i}), cropland use (n_{i}), and irrigation water use (w_{i}) by crop; the dependent variables are formed from these data. The survey also includes questions on irrigation technology, water sources, and water management practices; several independent variables are formed from these data. Table 1 reports descriptive statistics for several variables. Additional description of the data and variables is available from the authors.

The producers in the sample irrigate with groundwater only or with groundwater and surface water. Groundwater is assumed to be the marginal source when both sources are used. An engineering formula translates groundwater pumping lift into marginal pumping cost in dollars per acre-foot;[3] this cost serves as the measure of water price. Measuring price in this way assumes that state groundwater institutions do not impose binding constraints for water on irrigators.

Farms included in the sample grow at least two of the five common field crops and do not grow specialty crops (orchards, berries, and vegetables). Table 1 reports the number of farms growing each crop (that is, the nonlimit observations of each crop).

Secondary data sources are used to create variables to merge with the FRIS-based variables. Three categories of variables are defined: output and input prices; climate and weather; and soil quality. Crop price variables are constructed as expected 1984 and 1988 prices, based on econometric-based predictions using state-level time-series data from USDA. Variable input prices are current-year prices. They include farm-level water prices computed from FRIS data, and state-level wages and regional-level bulk-purchased gasoline prices from USDA.

Two climate variables represent expected weather conditions for a season: county-level growing season precipitation and cooling degree-days, based on thirty-year averages from NOAA weather stations. They help to explain crop choice, supply, and land allocation. Two weather variables represent actual conditions for the 1984 and 1988 seasons: crop-specific, county-level growing season precipitation and cooling degree-days, computed from NOAA records. They help to explain short-run water use. Soil variables represent cropland quality, including soil texture and land class. They are average county cropland values from the 1982 Natural Resources Inventory.

Econometric Methods

The availability of microdata on multicrop production presents an issue concerning application of an unbiased estimator.[4] To produce unbiased estimates, limited-dependent variable econometric models must be applied because many farms do not produce some of the crops in a multicrop system. Producers in the sample used here grow two or more of five field crops, with a value of zero representing a lower threshold for output, land use, and water use.

We apply two common approaches for analysis of limited-dependent variables, the Tobit model and the Heckman model (Maddala, p. 149–56 and p. 231–34).One major distinction between the Tobit and Heckman models concerns the exogenous variables explaining the quantity decision (Maddala; Bockstael et al.). In the Tobit model, the same set of exogenous variables explains both the participation and the quantity decisions. Behaviorally, the relatively long-run nature of the crop supply functions and land allocation functions is consistent with the Tobit. Farm-level exogenous variables (e.g., farm-level irrigation technology and climate) influence both the participation and quantity decisions. In the Heckman model, in contrast, the set of exogenous variables varies across decisions. Choices associated with short-run water demand are consistent with the Heckman model. The discrete decision to use water is affected by variables that also influence irrigated land allocation: a decision to allocate land to a crop means that irrigation water will be applied to that crop. Yet the quantity of water used during the irrigation season depends on short-run variables, including crop-level irrigation technology and weather.

Thus, the land allocation and supply functions [equations (3) and (7)] are estimated with the Tobit. The water demand functions [equa-

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[3] To compute a water price for each farm observation, energy cost for each fuel source is computed from farm-level FRIS data on groundwater pumping depth and pumping pressure (see table 1) by applying the formula (Gilley and Supalla, p. 1785): $C = P^*(1.3716/E)^*(L + 2.31^*PSI)$,where C=groundwater pumping cost in \$/acre-foot, P=fuel price, E=fuel efficiency, L=distance in feet that groundwater is lifted from the water table, PSI=pumping pressure in pounds per square inch, and 1.3716 and 2.31 are constants. Units for P and E correspond according to fuel type. In the computation, costs by fuel source (natural gas, LP gas, electricity, diesel, and gasoline) are combined based on farm acres served by each fuel. Variation in pumping depth, pressure, and fuel sources, along with differences in fuel prices, translate into variation in the water price variable.

[4] A second issue concerns efficient estimates. With multioutput systems, "...efficient econometric estimation generally requires estimation of a seemingly unrelated multiple-product system" (Shumway, Pope, and Nash, p. 75). System estimation techniques, however, are not available for limited-dependent variable models. Thus, we apply single-equation models to obtain unbiased estimates.

Table 1. Descriptive Information for Selected Variables

Item	Units	Region			
		Northwest	Central Plains	Southwest	Southern Plains
FARM-LEVEL VARIABLES					
Number of farms		361	766	403	912
Farm area	Acres				
Mean		1,187	1,455	2,053	1,146
Standard deviation		1,268	1,587	6,137	1,295
Water applied	Acre-feet				
Mean		2,073	2,074	6,836	1,562
Standard deviation		2,602	2,967	20,908	1,977
Water price	$/acre-foot				
Mean		18.99	16.81	23.81	23.32
Standard deviation		8.57	7.18	18.16	9.78
Normalized water price	$/acre-foot/NP[a]				
Mean		18.14	16.12	23.41	23.08
Standard deviation		8.30	6.74	17.67	9.58
Pumping depth	Feet				
Mean		151	99	153	179
Standard deviation		131	69	142	98
Pumping pressure	Pounds/inch^2				
Mean		59	39	18	25
Standard deviation		17	20	21	17
Cooling degree-days	Degree-days				
Mean		3,730	4,776	8,040	6,405
Standard deviation		801	915	1,479	796
Growing season precipitation	Inches				
Mean		4.42	12.92	10.09	14.23
Standard deviation		1.32	3.45	4.72	2.81
Normalized wage rates	$/hour/NP				
Mean		4.02	4.07	4.71	3.88
Standard deviation		0.72	0.78	0.88	0.38
Bulk gasoline[b]	$/gallon				
Mean		1.05	1.05	1.02	1.01
Standard deviation		0.11	0.10	0.08	0.08
Surface water available	% of farms	46	23	62	7
Pressure irrigation technologies available	% of farms	93	77	22	57
Water management method on farm					
Advanced methods used	% of farms	22	37	18	20
Fixed-time methods used	% of farms	24	17	28	14
CROP-LEVEL VARIABLES					
Count of non-limit observations					
Alfalfa	farms	270	464	255	200
Barley	farms	271	96	NA[c]	NA
Corn	farms	47	667	90	378
Cotton	farms	NA	NA	321	361
Dry beans	farms	51	191	NA	NA
Sorghum	farms	NA	NA	40	546
Wheat	farms	282	446	258	715
Mean acres[d]					
Alfalfa	acres/farm	337	281	368	212
Barley	acres/farm	308	205	NA	NA
Corn	acres/farm	231	772	293	493
Cotton	acres/farm	NA	NA	1,209	461
Dry beans	acres/farm	247	294	NA	NA
Sorghum	acres/farm	NA	NA	159	347
Wheat	acres/farm	437	424	504	481

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Table 1. Continued

Item	Units	Region Northwest	 Central Plains	 Southwest	 Southern Plains
Mean water applied[d]					
Alfalfa	acre-feet/farm	710	503	1,491	585
Barley	acre-feet/farm	451	269	NA	NA
Corn	acre-feet/farm	611	1,224	993	916
Cotton	acre-feet/farm	NA	NA	4,396	507
Dry beans	acre-feet/farm	531	324	NA	NA
Sorghum	acre-feet/farm	NA	NA	459	441
Wheat	acre-feet/farm	615	429	1,337	529
Mean output[d]					
Alfalfa	tons/farm	1,534	1,290	2,485	1,124
Barley	bu/farm	26,013	12,835	NA	NA
Corn	bu/farm	33,917	115,402	37,877	75,997
Cotton	bales/farm	NA	NA	2,710	598
Dry beans	cwt/farm	5,181	5,984	NA	NA
Sorghum	bu/farm	NA	NA	14,222	32,003
Wheat	bu/farm	36,491	23,468	47,408	25,924

Note: Descriptive statistics for the remaining variables are not reported due to space constraints. A complete description of data sources and variable construction is available from the authors.

[a] NP represents the input price used as the *numéraire* price.

[b] Bulk gasoline is the input price used as the *numéraire* price.

[c] NA is "not applicable" because crop not grown in region.

[d] Crop-level means apply only to the farms growing that particular crop.

tion (8)] are estimated with the Heckman model.[5] Crop-choice decisions [equation (1)] are estimated with a probit model. These functions are estimated for five crops in each region ($m = 5$), and four regions in total. All of the estimation is conducted as single-equation regressions using LIMDEP computer software (Greene).

A final topic involves the technique applied in the interregional comparisons of whether the parameters of individual functions are constant across the regions with common crops (Northwest versus Central Plains and Southwest versus Southern Plains). These comparisons are implemented as Chow tests (Fomby, Hill, and Johnson, p. 47–48). The test assesses, for instance, whether the parameters of an alfalfa supply function are constant across the Northwest and Central Plains.

Chow Tests for Structural Differences Across Regions

The Chow tests examine rigorously the issue of whether similarities in cropping pattern among irrigators in different regions translate into structural similarities in observed output and input decisions. In effect, the tests examine whether parameters of a multioutput technology are constant across regions. The experiment here is interesting because the five-crop cropping pattern is held constant across regions.

For every crop and its four estimated equations, the Chow tests are applied across the Northwest and Central Plains regions and, independently, across the Southwest and Southern Plains regions. The tests are implemented as likelihood ratio tests (via a χ^2 test) for equations estimated with maximum likelihood procedures (crop-choice, land allocation, and supply) and as an F test for equations estimated with OLS (water demand, since the Heckman uses OLS in its second stage). The null hypothesis for the tests is that the parameters are constant across regions.

Almost universally, the results reject the null

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[5] Note that the land allocation equations and water demand equations do not need to be estimated as a simultaneous equation system. This set of equations is diagonally recursive (Kmenta, p. 586). Here, diagonally recursive means that, while crop-level water use depends on crop-level land allocation, the reverse is not true. This situation thus creates no particular problem, e.g., ordinary-least-squares estimates are unbiased and efficient with a diagonally recursive system.

hypothesis.[6] Consider first the structural comparisons across the two northern regions. The null hypothesis of no structural differences across the Northwest and Central Plains regions is rejected at the 0.01 significance level for each of the fifteen equations representing relatively long-run decisions (crop-choice, supply, and land allocation). In the short-run water demand equations, the null hypothesis of no differences across regions is rejected at the 0.01 level for three of five crops. The exceptions are alfalfa and barley water demands, for which the null hypothesis cannot be rejected at the 0.01 level.

The comparisons across the southern regions also yield strong statistical evidence of structural differences across the Southwest and Southern Plains regions. Every null hypothesis of no structural difference across the two regions is rejected at the 0.01 significance level.

The Chow tests show clearly that, even with identical cropping patterns, region-specific estimation of choice equations is generally appropriate. This conclusion is consistent with Polson and Shumway's findings on the structure of technology across states in the south-central U.S.

Water Price as a Determinant of Producer Decisions: Evidence for Four Western Regions

The following section focuses on the performance of water price to distill the key results from the equations: eighty equations (twenty equations per region) are estimated by applying (1), (3), (7), and (8).

General Empirical Findings

The econometric results produce four general findings. For context here, refer to table 2 for two items: (*a*) elasticities with respect to water price, based on the eighty estimated equations, and (*b*) statistical significance of the eighty estimated coefficients for the water price variables.

Finding 1. In the decomposition of crop-level water demand into extensive and intensive margins, water price is significant at the extensive margin in fourteen of twenty optimal land allocation equations, but is universally statistically insignificant at the intensive margin of short-run water demand.

Two general patterns are clear. One, water price was not negative and significant in any of twenty short-run water demand equations.[7] After choosing cropland allocations, water price simply does not affect producers' short-run water use.

This important result indicates that, in terms of the effect of water price on multicrop profits, the major impact occurs through crop-choice, irrigation technology, and land allocation decisions. Once cropland is allocated, the level of water price appears not to have a major quantitative impact on profit; otherwise, water price would be a significant determinant of short-run water use. This result also implies that, for price-induced water conservation to be effective, it must rely on responses through cropland allocation or irrigation technology adoption.

Two alternative models may explain producer decisions on short-run water use better than the variable input model. A "behavioral" model (Just et al. 1990) relates water use primarily to acreage in the crop. According to this model, producers apply a fixed water-land ratio in the short-run.[8] Second, a fixed, allocatable input model offers a more complex model of multicrop decisions than the behavioral model. In this model, producers operate with a short-run constraint on farm-level water use because of fixed groundwater pumping capacity. This constraint invokes a competition among crops for water. Both alternative models are consistent with the notion that, once acreage decisions are made at the start of the season, water price does not affect water use.

The second general pattern is that, although the extensive margin responds to water price, this is not universally true for all crops. In three of four regions, adjustments in land allocation occur for some, but not all, crops. The Southern Plains is the exception, with the water price

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[6] A table reporting crop-specific results for the Chow tests is available from the authors.

[7] The Heckman model can create multicollinearity problems by introducing the variable used to correct for selectivity bias (Bockstael, et al.). To assess whether the weak statistical performance of the water price variables was caused by multicollinearity, the Cragg model was estimated as an alternative to the Heckman. The Cragg model does not introduce multicollinearity. In estimates using the Cragg model, the water price variables were also statistically insignificant at the 0.10 level.

[8] Just et al. (1990) did not develop specific results on the statistical significance of water price in explaining short-run water use in multicrop systems. An interesting aspect of the current research is that the data set yields results on water price as a determinant of short-run water use.

variable significant at the 0.01 level in all five land allocation equations. In total, fourteen of twenty estimated coefficients are significant at the 0.10 level. With so many statistically significant responses, insignificant coefficients appear to be an accurate representation of producer decisions, i.e., they indicate that water price does not influence land allocation for a limited number of crops.

Note that responsiveness to water price can be viewed as farm-level land reallocations that would occur with an increase in price. In every region, some land allocations increase in price while others decrease. This is consistent with theory, as the farm-level land constraint requires that coefficients sum to 0 within a region. Empirically, of course, crops with different water requirements should tend to be substitutes. This occurs in the Southwest, for example, where alfalfa acreage declines in water price while cotton acreage increases for the sample analyzed.

Finding 2. The majority of responses to water price at the extensive margin are moderately to highly inelastic.

We found that twelve of twenty land allocation elasticities with respect to water price fall below 0.5 in absolute value, indicating limited response to water price in general. Three crops respond elastically in certain regions, however: barley in the Central Plains, and alfalfa and cotton in the Southern Plains.

Finding 3. For an individual crop in a particular region (e.g., alfalfa in the Northwest), the sign and statistical significance of water price generally is very similar in determining relatively long-run decisions across the crop-choice, land allocation, and crop supply equations.

The three relatively long-run equations perform comparably with respect to water price. Across the three equations for a given crop and region, the sign on water price is identical and the statistical significance is similar (with fourteen of twenty significant coefficients for the land allocation and crop supply equations, and fifteen of twenty significant coefficients for the crop-choice equations, all evaluated at the 0.10 significance level). In particular, both the magnitude of the elasticity and the significance of the underlying water price estimates are closely comparable across land allocation and supply equations. Alfalfa illustrates this vividly. By region, its land allocation and supply elasticities, respectively, are: –0.53 and –0.51 in the Northwest; –0.58 and –0.50 in the Central Plains; –0.30 and –0.32 in the Southwest; and –1.48 and –1.46 in the Southern Plains.

This correspondence between land allocation and supply provides useful information on output substitution in response to water price. In principle, output substitution should be analyzed with supply functions. As demonstrated here, however, the land allocation elasticities offer a de facto surrogate for supply response for the case of these irrigated field crops.

Finding 4. For an individual crop (e.g., corn), regions generally differ in the statistical significance and/or sign of water price as a determinant of relatively long-run decisions.

This finding shows the importance of accounting for structural differences across regions. The analysis holds constant the five crops produced in the northern regions. Still, barley switches from a crop whose long-run decisions increase in water price in the Northwest to the opposite in the Central Plains. Corn, wheat, cotton, sorghum, and (to a degree) dry beans also exhibit this finding.

The lone exception to the finding is alfalfa, a crop with heavy water requirements. Producers clearly substitute away from alfalfa production in the face of higher water prices.

Decomposing Farm-level Water Demand

Examining the relationship between farm-level water demand and crop-level water demands involves decomposing farm-level water demand into the sum of crop-level water demands, and then further decomposing crop-level demand into intensive and extensive margins of water use. Equation (10) states this succinctly for a given change in water price. This equation is applied in each of the four regions to assess response to a water price change.

The basic elements of farm-level water demand consist of the estimated coefficients on water price in the land allocation and short-run water demand equations: a marginal change in short-run water use given a change in water price ($\partial w_i/\partial b$), a change in short-run water use given a change in land use ($\partial w_i/\partial n_i$), and a change in land use given a change in water price ($\partial n_i/\partial b$), for every crop, $i = 1 - 5$. Using (10), we combine the elements in three steps to assemble farm-level water demand: (*a*) multi-

Table 2. Elasticities with Respect to Water Price

	Northwest (NW) and Central Plains (CP)							
	Crop choice		Land allocation		Crop supply		Short–run water demand	
Crop	NW	CP	NW	CP	NW	CP	NW	CP
Alfalfa	–0.26**	–0.29**	–0.53**	–0.58**	–0.51**	–0.50**	0.07	–0.07
Barley	0.19**	–1.01*	0.24*	–1.56**	0.27*	–1.59**	–0.14	–0.06
Corn	–0.89	0.03*	–0.68	0.18*	–0.62	0.18*	0.12	0.05
Dry beans	0.92*	0.35	0.97*	0.31	0.95*	0.31	0.03	0.21*
Wheat	0.23**	0.26**	0.17	0.28*	0.20	0.28*	–0.11	0.12

	Southwest (SW) and Southern Plains (SP)							
	Crop choice		Land allocation		Crop supply		Short–run water demand	
Crop	SW	SP	SW	SP	SW	SP	SW	SP
Alfalfa	–0.28**	–1.14**	–0.30**	–1.48**	–0.32**	–1.46**	–0.05	–0.10
Corn	–0.28	0.25*	–0.38	0.56**	–0.38	0.64**	0.04	0.08
Cotton	0.17**	–1.04**	0.17**	–1.33**	0.21**	–1.38**	–0.13	0.12
Sorghum	–0.26	0.33**	–0.27	0.34**	–0.31	0.42**	–0.05	–0.06
Wheat	0.09	0.14**	0.02	0.37**	0.005	0.38**	0.07	0.10

* denotes significance at the 0.10 level and ** at the 0.01 level on the estimated water price coefficients used in calculating the elasticity values from the respective equations.

ply together $\partial w_i/\partial n_i$ and $\partial n_i/\partial b$ to obtain the extensive margin for each crop, with the intensive margin already represented in $\partial w_i/\partial b$,[9] (*b*) add together the two margins to obtain the set of crop-level responses, and (*c*) add the crop-level responses to produce farm-level response. In addition to these three steps taken from theory, the use of limited-dependent variable econometric models requires two adjustments to account for producers who do not grow a particular crop.[10] The term $(\partial w_i/\partial n_i)(\partial n_i/\partial b)$ is multiplied by the probability that a producer from the sample actually grows the crop (following McDonald and Moffitt). The term $\partial w_i/\partial b$ is also conditioned to reflect the influence of producers who do not grow the crop [following equation (16) in Bockstael et al.]. Table 3 reports the numerical results from application of this procedure.

A certain perspective on the analysis can be illustrated with the numerical results on crop-level and farm-level response in water use (in the right-hand column of table 3). Crop-level response represents the sum of a direct adjustment at the intensive margin (holding acreage constant) and an indirect adjustment operating through land allocation at the extensive margin. Taking the Northwest as an example, a \$1 increase in water price ($\Delta b = 1$) in a multicrop farm setting would induce: a decrease in alfalfa water use of almost 22 acre-feet; a decrease in corn water use of over 2 acre-feet; and an increase in barley, dry beans, and wheat water use of roughly 4 acre-feet for each crop. These responses demonstrate the importance of adjusting intercrop use of water and land resources as a multicrop producer response to water price.

The crop-level responses partially offset each other when computing a farm-level response. Farm-level water use decreases by roughly 12 acre-feet as the net effect of a \$1 increase in water price. For an "average" farm applying 2,073 acre-feet—the mean level of total water use in the Northwest (table 1)—water use would only decline to 2,061 acre-feet.

Findings 5–8 describe empirical results associated with decomposing water demand.

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[9] Even though the coefficients on water price ($\partial w_i/\partial b$) are statistically insignificant in the short-run water demand equations, they still represent statistically unbiased estimates and, thus, can be used as appropriate predictors of behavior.

[10] Coefficients from both the Tobit and Heckman models must be adjusted before they are used to interpret observed behavior. Because the Tobit specifies a latent variable framework for the dependent variable, its coefficients represent marginal changes in the latent, rather than the observed, variable. Because the second stage of the Heckman uses only nonlimit observations, its coefficients represent only those producers who grow the crop rather than the entire sample.

Table 3. Decomposing Farm-level Water Demand: Marginal Adjustments to Water Price at the Crop-Specific Extensive and Intensive Margins

Region and Crop	$(\partial w_i/\partial n_i)$[a]	$(\partial n_i/\partial b)$[b]	$F(x)_i$[c]	Extensive margin[d]	Intensive margin $(\partial w_i/\partial b)$[e]	Total effect[f]
Northwest						
Alfalfa	2.16	–11.99	0.75	–19.42	–2.39	–21.81
Barley	1.44	4.53	0.75	4.89	–1.10	3.79
Corn	2.96	–5.70	0.13	–2.20	–0.19	–2.39
Dry beans	3.34	9.20	0.14	4.34	0.10	4.44
Wheat	1.58	4.98	0.78	6.16	–1.92	4.24
Farm total						–11.72
Central Plains						
Alfalfa	2.06	–14.36	0.61	–17.91	–5.05	–22.96
Barley	1.29	–13.95	0.13	–2.26	–0.32	–2.58
Corn	1.95	8.61	0.87	14.64	4.53	19.17
Dry beans	0.98	4.06	0.25	0.99	1.21	2.20
Wheat	1.22	6.41	0.58	4.54	3.62	8.16
Farm total						3.99
Southwest						
Alfalfa	4.07	–6.26	0.63	–16.13	–15.49	–31.62
Corn	3.08	–4.99	0.22	–3.43	–1.39	–4.82
Cotton	3.43	7.39	0.80	20.18	0.47	20.66
Sorghum	3.73	–1.46	0.10	–0.54	–1.70	–2.24
Wheat	3.71	0.73	0.64	1.74	–0.61	1.14
Farm total						–16.88
Southern Plains						
Alfalfa	3.06	–10.19	0.22	–6.85	–2.19	–9.04
Corn	1.93	10.69	0.41	8.55	2.32	10.87
Cotton	1.00	–28.58	0.40	–11.28	–5.30	–16.58
Sorghum	1.29	5.23	0.60	4.05	1.95	6.00
Wheat	1.11	7.38	0.78	6.40	0.19	6.59
Farm total						–2.16

[a] $\partial w_i/\partial n_i$ is the estimated coefficient on own-crop acreage in the short-run water demand equations, where w_i is acre-feet of water used on crop i and n_i is acres in crop i.

[b] $\partial n_i/\partial b$ is the estimated coefficient on water price in the land allocation equations, where b is the normalized water price in \$/acre-foot/NP.

[c] $F(x)_i$ is the share of the sample growing crop i. It is used here as in McDonald and Moffitt to reflect that each crop is grown by only a share of producers in the sample.

[d] The extensive margin, $\partial w_i/\partial n_i$ times $\partial n_i/\partial b$ times $F(x)_i$, represents the change in crop-level water use (acre-feet/farm) from changes in land use as result of a marginal adjustment in water price.

[e] $\partial w_i/\partial b$ is the estimated coefficient on water price in the short–run water demand equations adjusted by the estimated probability the crop is grown and the change in probability of growing the crop given the estimated coefficient (as in Bockstael et al.). It represents the direct change in crop-level water use (acre-feet/farm) from a marginal adjustment in water price.

[f] The crop-level total effect is the sum of the extensive margin and the intensive margin, by crop. The farm-level total effect, dW/db, is the sum of the crop-level total effects (see equation 10).

Finding 5. At the crop-level, responses at the extensive margin outweigh the intensive margin in absolute value for eighteen of the twenty crop/region combinations.

Finding 5 establishes the dominance of the extensive margin. Table 3 shows that the coefficients on water price in the land allocation equations, $\partial n_i/\partial b$, determine this finding for most cases. These coefficients, most of which exceed 4 in absolute value, serve as a strong magnifying effect on the extensive margin. In contrast, the influence of the limited-dependent variable regression models serves as a contractionary effect on the extensive margin; multiplying through by the share of the sample growing the crop $[F(x)_i]$ diminishes the final product for the extensive margin.

Finding 6. Eleven of twenty crop-level responses are positive because the pertinent crops' land allocations respond positively to water price. Nine of twenty crop-level responses, for the same reason, are negative.

Finding 6, on the qualitative sign of crop-level response, complements Finding 5 on the relative quantitative significance of the extensive and intensive margins. As with 5, this finding relates to the dominance of the extensive margin. That is, with water use responding positively to acreage for every crop ($\partial w_i/\partial n_i > 0$), the sign of $\partial n_i/\partial b$ dictates the sign of crop-level response.

The information on crop-level responses reveals the complexity of producer behavior in a multicrop setting. Land allocations are the quantitatively important responses to water price, and more than half of them increase in price. This is intuitively appealing, as substitution toward production of less water-intensive crops provides a natural reaction to a higher water price.

Finding 7. Although many crop-level responses are positive, the farm-level response is negative for three of four regions.

When assembled according to (10), the individual elements create a negative coefficient on water price for three of the four region's farm-level water demands, with the Central Plains the exception (table 3). These assembled coefficients represent the marginal change in farm-level water use, in acre-feet, given a marginal increase in water price. The negative coefficients are consistent with theory: multioutput input demand slopes downward in price. In contrast, the positive coefficient in the Central Plains is inconsistent with theory, and should be used with caution.

Finding 8. The farm-level elasticity of demand with respect to water price is highly inelastic for every region.

Converting the coefficients to elasticities yields a yardstick for comparison. The elasticities are evaluated at the variables' means for W and b (see table 1 for the means). Farm-level responses are highly inelastic in every region: –0.10 in the Northwest, –0.06 in the Southwest, –0.03 in the Southern Plains, and 0.03 in the Central Plains. Farm-level price elasticities of water demand from prior research also are moderately to highly inelastic, generally falling below –0.40. Recent econometric estimates are –0.25 in the Texas High Plains (Nieswiadomy) and in the range of –0.07 to –0.26 for western irrigated agriculture (Ogg and Gollehon). Arc elasticities of demand from programming studies range from –0.20 to –0.97 in California (Howitt, Watson, and Adams) and –0.22 to –0.40 in the Columbia Basin of Washington (Bernardo et al.).[11] While informative, the comparison to prior research cannot be made too closely for two reasons: the water price variable here is a normalized price and, as shown by Shumway and Chang, conclusions typically should not be drawn about the quality of elasticity estimates when comparing results from programming and econometric methods.

Estimated Equations for the Northwest

This section discusses selected results for the Northwest to demonstrate the performance of the general modeling framework and empirical specifications. Two tables report the results: land allocation functions, in table 4, and short-run water demand functions, in table 5. The crop supply and crop-choice functions, although not reported, apply the same set of exogenous variables as the land allocation functions.[12]

The previous section already reported that land allocations functions can substitute for crop supply functions in analysis of output substitution. In the Northwest, the land allocation results indicate that a higher water price would induce substitution of barley and dry bean acreage and output for alfalfa acreage and output. This depiction appears reasonable, as it describes a substitution of crops with low water requirements for a crop with a high water requirement. Other specific results with the land allocation equations follow (table 4). The land constraint, as expected, plays a statistically significant role in determining land allocations. The estimated coefficient on the constraint shows the marginal increase in a crop's acreage when the constraint is relaxed ($\partial n_i/\partial N$). (Multiplying the estimated coefficients by the value of $F(x)_i$ in table 3 provides an estimate of $\partial n_i/\partial N$ for observed behavior rather than for the Tobit's latent variable model.) Further, several variables that are statistically significant in explaining crop-choice decisions of certain crops—surface water availability, cooling degree-days, and high- and low-quality soil—also

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[11] The Columbia Basin numbers (derived from Bernardo et al.) are computed from implicit price increases from \$12.60 to \$41.76, and then to \$97.20, per acre-foot for a center pivot irrigated farm.

[12] A lengthier discussion of the Northwest results and tables of crop-choice equations and crop supply functions are available from the authors.

Table 4. Tobit Model Estimates of Land Allocation Functions, Northwest Region

Independent variable	Alfalfa	Barley	Corn	Dry beans	Wheat
Output and input prices					
ALFPRC	1.72	3.58	−64.93	36.98	8.41
BARPRC	1071.30*	987.28*	657.16	−1003.50	−3129.80**
CRNPRC	308.11	465.74	−455.82	−2723.80	−610.98
DBNPRC	−26.37	−26.41	−99.52	283.54	110.85
WHTPRC	−363.22	−495.23	1262.80	−1669.10	951.59
WTRPRC	−11.99**	4.53*	−5.70	9.20*	4.98
WAGE	46.13	−15.22	871.85*	−773.44	−573.17**
Farm-level land constraint					
TOTACR	0.13**	0.19**	0.11**	0.06*	0.45**
Other exogenous variables					
DMSRWT	17.28	−62.18	348.41**	22.48	−257.58**
DMPRES	235.26*	46.29	−95.10	−244.42*	−87.81
CLMCDD	−0.03	−0.18**	0.85**	0.43**	0.08*
CLMPCP	44.97*	−21.25	41.51	53.98	0.09
SAND	181.48	611.63**	13.36	144.31	−243.91
GOODSL	−133.20*	−62.86	−73.01	96.30	184.05**
BADSL	144.28*	−304.00**	−54.16	−113.67	−278.98*
INTERCEPT	−2005.80	−927.01	−6086.00	7902.00	4772.70
SEE[a]	430.79	352.32	455.17	427.11	537.99
LLF[b]	−2085.28	−2029.49	−397.19	−442.27	−2222.10

* and ** denote significance at the 0.10 and 0.01 levels, respectively.

Note: Dependent variable is crop acreage.

[a] Standard error of the estimate. Dividing the estimated regression coefficients by the SEE produces normalized coefficients for the latent dependent variable model of the Tobit.

[b] Value of log likelihood function.

Variable definitions: All prices are normalized by the price of bulk gasoline. See table 1 for units. ALFPRC—alfalfa hay price; BARPRC—barley price; CRNPRC—grain corn price; DBNPRC—dry beans price; WHTPRC—wheat price; WTRPRC—water price calculated as the farm-level groundwater energy cost; WAGE—farm labor wage rate; TOTACR—total farm area in crop production; DMSRWT—binary variable indicating surface water used on the farm; DMPRES—binary variable indicating pressurized irrigation technology on the farm; CLMCDD—long-run base 55 cooling degree-days; CLMPCP—long-run precipitation; SAND—binary variable representing relatively sandy soil; GOODSL—binary variable representing soil with relatively few use restrictions; and BADSL—binary variable representing soil with relatively many use restrictions.

make sense intuitively in explaining land allocation decisions for many of the same crops. For example, both in the crop-choice and land allocation equations, average cooling degree-days is significant at the 0.01 level in determining barley, corn, and dry beans decisions. Producers tend to grow barley in relatively cool areas of the Northwest and corn and dry beans in warm areas. This corresponds to the crops' relative temperature tolerances.

The primary result of general importance with the short-run water demand functions is the statistical insignificance of water price (table 5), which was discussed previously. Most notable among the other independent variables is crop acreage; not surprisingly, it is a significant determinant of the total quantity of water applied to the crop. The coefficient on crop acreage indicates the marginal change in water application given a marginal change in acreage $(\partial w_i/\partial n_i)$ for producers growing the crop. A one-acre increase in land, for example, results in incremental acre-feet increases in water of: barley, 1.44; wheat, 1.58; alfalfa, 2.16; corn, 2.96; and dry beans, 3.34.[13]

Summary and Conclusions

We analyzed several responses to water scarcity that are available to multicrop producers in irrigated agriculture. A multioutput production

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[13] The coefficients should not be interpreted as the water used on the additional acre of land. For the case of corn, for instance, the coefficient implies that, with an increase of one acre in corn acreage, 2.96 additional acre-feet of water are applied to total corn acreage. In other words, the total amount of water increases by 2.96, and the new total water will be applied over the new total amount of acreage. Average water application rates will change only slightly in response to the marginal increase in water use created by a marginal increase in acreage.

Table 5. Heckman Model Estimates of Short-run Water Demand, Northwest Region

Independent variable	Alfalfa	Barley	Corn	Dry beans	Wheat
Output and input prices					
OWNPRC	0.55	-2.11	187.03	-17.91	126.57
WTRPRC	2.77	-3.28	4.94	0.78	-3.49
WAGE	54.80	-23.22	29.94	-169.27	-133.41
Own-crop acreage					
OWNACR	2.16**	1.44**	2.96**	3.34**	1.58**
Other exogenous variables					
DMSRWT	135.76*	152.54*	18.93	-292.61*	202.74**
DMOWNTC	-153.37	-5.36	-61.64	-322.88*	-36.44
DMNOWT	45.96	4.72	55.19	88.56	-104.04
DMLWMG	-4.16	-41.45	37.00	288.46*	-19.97
DMHGMG	60.66	-33.99	-52.22	-39.99	-15.48
OWNCDD	0.04	0.18*	-0.28**	0.52	0.13*
OWNPCP	13.41	-7.13	-30.00	-197.35*	-10.54
SAND	354.66	374.24	51.61	42.49	188.01
INTERCEPT	-468.58	-7.73	-118.23	-121.42	-170.56
I MILLS[a]	152.99	-192.36	-78.20	439.93	244.11
Adjusted R^2	0.74	0.67	0.99	0.80	0.87

* and ** denote significance at the 0.10 and 0.01 levels, respectively.

Note: Dependent variable is water applied to the crop in acre-feet.

[a] I MILLS is the inverse Mills ratio, which is a variable created when applying the Heckman model.

Variable definitions: All prices are normalized by the price of bulk gasoline. See table 1 for units. OWNPRC—own crop price; WTRPRC—water price calculated as the farm-level groundwater energy cost ; WAGE—farm labor wage rate; OWNACR—own crop acreage; DMSRWT—binary variable indicating surface water used on the farm; DMOWNTC—binary variable indicating pressurized irrigation technology on the crop; DMNOWT—binary variable indicating farm discontinued irrigation water use long enough to affect yields; DMLWMG—binary variable indicating farm relied on fixed-time water management practices; DMHGMG—binary variable indicating farm relied on advanced water management practices; OWNCDD—actual base 55 cooling degree-days over the growing season for each crop; OWNPCP—actual precipitation over the growing season for each crop; SAND—binary variable representing relatively sandy soil.

model of the firm is developed to separate farm-level irrigation water demand into its constituent elements. Farm-level demand initially decomposes into a series of crop-level water demands. Then, crop-level demands further separate into an extensive margin and an intensive margin of water use. The analysis thus examines a variety of responses to higher water prices.

Two key empirical findings on the role of water price illustrate new insight into multioutput producer behavior in the western United States. One, observed activity at the farm-level masks crop-level adjustments. For example, farm-level water use typically declines in water price, yet crop-level water use declines in water price for some crops and increases for other crops. Further, farm-level water use responds very inelastically, while land allocation responses generally create much more elastic responses in crop-level water use. Two, in the context of irrigated field crop production, producers respond to water price at the extensive margin of water use (crop-choice and land allocation decisions) rather than the intensive margin (short-run water use decisions). Water price, in fact, is not negative in sign and statistically significant in explaining short-run water demand in any of twenty estimated equations. These two empirical findings indicate the richer description of producer behavior that becomes possible with crop-level microdata.

The econometric analysis also finds that, even while holding the set of crops constant in a multioutput context, structural differences in the estimated equations exist across regions. These results indicate that transferring econometric results across regions should be done cautiously.

Several limitations of the analysis are noted. First, the estimated parameters and elasticities cannot necessarily be used in more aggregate models of irrigated production. The sample used in the study applies only to multicrop producers who grow the set of crops analyzed. Second, our study does not pertain directly to producers who irrigate solely with surface water. Results may not be transferrable to this class of irrigators. Third, variables for crop prices, gasoline price, and wages have little cross-sectional variation. Instead, variation in these variables came from a two-year time series. Additional years of data should produce more accurate estimates for these variables.

At least two items of future research are important. Our empirical results can be extended to develop two components of a welfare analysis of water price increases: using the crop supply estimates to measure the change in producer's surplus from a price increase, and applying the farm-level water elasticities to provide estimates of water conservation from a price increase. Lastly, alternative models of short-run input use in multicrop systems can be formally compared to the present paper's variable input model. The ineffectiveness of water price suggests that an acreage-based model or a fixed, allocatable input model of water use may better explain short-run decisions.

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